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B. Kolundžija

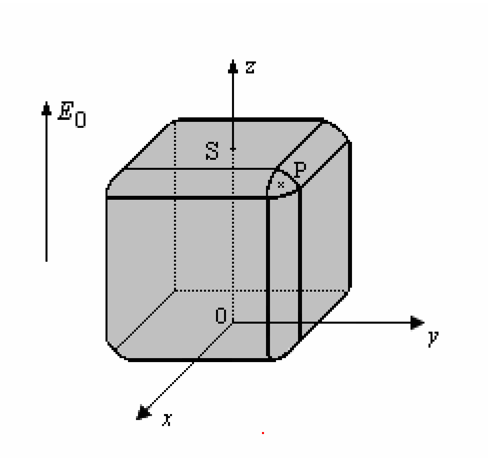
Electric Field Calculation of Cube Electrode with Rounded Wedges

ABSTRACT

In this paper the electric field and potential in vicinity of the conducting cube with rounded wedges immersed in homogeneous incident field is investigated by using specific Equivalent Source Method (ESM). Dependences of the resulting electric field in the center of rounded wedges and in the center of rounded vertices are shown versus the ratio of the cube wedge length and the radius of wedge curvature.

INTRODUCTION

Metallic wedges and vertices by their nature, are places where charges gather in conductors. Theoretically speaking, when wedges are considered to be ideal (radii of the wedge curvature tends to zero) the electric field is infinitely large. In practice, the wedges are always more or less rounded. However, if they are not enough rounded, the electric field can become so large that breakdowns can occur. This can happen even if metallic body with wedges and vertices is placed in homogenous electric field (e.g., truck in atmospheric electric field during stormy weather, Ref.1).



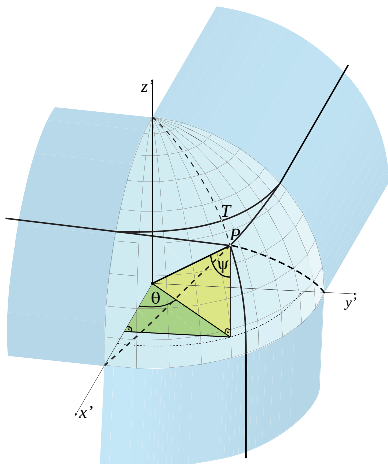


Fig.1 - Metallic cube of wedge length a.

The aim of this paper is to investigate how large can become electric field in the vicinity of real life wedges and vertices of huge metallic bodies immersed in homogenous electric field. The investigation is performed on the example of metallic cube of wedge length a. Wedges are rounded having radius of curvature r, Fig.1. Precise modelling is done using specific Equivalent Source Method (ESM), which can be considered as combination of methods shown in Refs. 2 and 3.

EQUIVALENT SOURCE METHOD APPLICATION

Positions and types of equivalent sources are chosen to achieve high accuracy of electric field calculations in all regions in vicinity of rounded cube, including wedges and vertices. The equivalent sources are placed over the surface of an inner cube (with sharp wedges) of wedge length $a_1 = a - 2r$, Fig. 2. Each side of inner cube is subdivided into square subsurfaces, $\Delta x = \Delta y = \Delta z = a_1 / N$. Basic type of equivalent sources is in form of charges uniformly distributed over these subsurfaces. In addition, equivalent sources in form of line charges are placed along wedges of the inner cube and equivalent sources in form of point charges are placed in vertices of the inner cube.

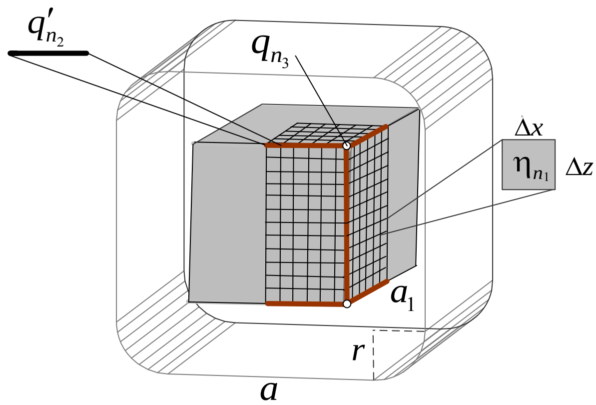


Fig. 2 - Distributions of equivalent sources.

Using the superposition principle potential (electric field) on the original cube surface is expressed in terms of unknown weights of equivalent sources:

$$\varphi = -E_0 z + \varphi(\eta) + \varphi(q') + \varphi(q), \tag{1}$$

where E_0 is the strength of the vertical oriented atmospheric electric field (AEF). The intensity of AEF is approximately $100\ \mathrm{V/m}$ - $200\ \mathrm{V/m}$ under fair weather conditions and can reach several thousand $\mathrm{V/m}$ under the clouds of an approaching thunderstorm.

Requiring that such potential (field) satisfy boundary condition in properly adopted points on the cube surface (matching points), Fig. 3, the system of linear equations is obtained.

$$\varphi = V,\ k = 1,2,\ldots, N_{\mathrm{u}}, \tag{2}$$

$$N_{\mathrm{u}} = N_1 + N_2 + N_3 = \frac{3N^2}{2} + 3N + 2,$$

where:

- The cube potential V is unknown, and could be determine from the condition that total charged the cube is equal to zero, i.e. $Q = 0$ and

- N_{u} is the total number of equivalent sources (N_1 is the number of equivalent sources in form of surface charges, N_2 is the number of equivalent sources in form of line charges and N_3 is the number of the point charges).

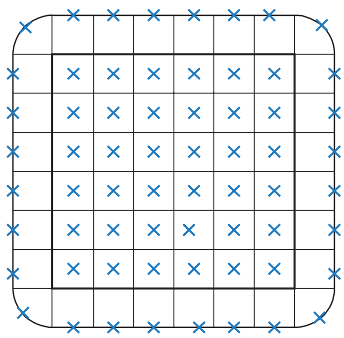


Fig. 3 - The matching points on one cube face.

After solving the system for unknown weight of equivalent sources (2) any other quantity of interest, including electric field in vicinity of the cube wedges and vertices can be easily determined as

$$E = -\mathrm{grad}\,\varphi \ . \tag{3}$$

It can be shown that electric field strength in the vicinity of real life wedges and vertices of huge metallic bodies depends of the ratio of the cube wedge length and radius of wedge curvature and intensity of the atmospheric electric field:

$$E = f\left(\frac{a}{r}\right). \tag{4}$$

NUMERICAL RESULTS

On the basis of the presented theoretical analysis a computer code is made and numerous calculations are performed. The part of obtained results will be presented in this paper.

Electric field in vicinity of rounded wedges and vertices of the cube are presented for different ratio of the wedge length and radius of wedge curvature, r/a. In particular, results are shown in the center of rounded vertices, which are most critical from the stand point of possible electric field breakdown. The convergence of the obtained results for electric field strength of the cube with number of used equivalent sources are presented in the **Table I** and **Table II** .

Table I

Convergence of the results of the electric field strength
in the center of the flat surface (point S (0, 0, 1), Fig. 1).

N	E/E_0			
	$r/a = 0.01$	$r/a = 0.005$	$r/a = 0.0025$	$r/a = 0.001$
10	1.654442	1.654702	1.653612	1.656749
20	1.654502	1.653985	1.655557	1.654299
30	1.654839	1.653895	1.653851	1.653823
40	1.655053	1.653797	1.653627	1.653666
50	1.655183	1.654502	1.653613	1.653603

Table II

Convergence of the results of the electric field strength of the cube
in the center of the rounded vertices
(point P($x = y = (\sqrt{3}/3 - 1)\,r + a/2$, $z = (\sqrt{3}/3 - 1)\,r + a$), Fig. 1).

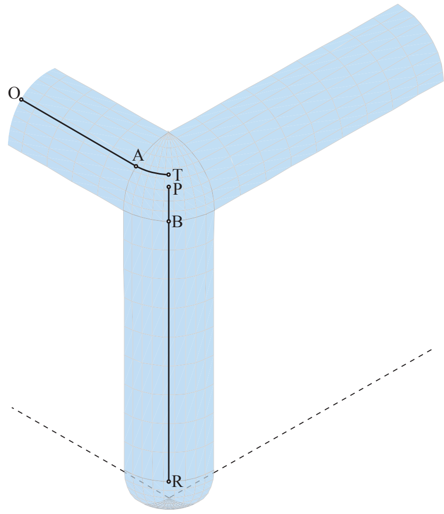
N	E/E_0			
	$r/a = 0.01$	$r/a = 0.005$	$r/a = 0.0025$	$r/a = 0.001$
10	12.584888	19.262151	31.341548	64.598187
20	12.769931	18.368906	28.109352	54.092578
30	13.200219	18.392685	27.136626	49.900849
40	13.616308	18.633397	26.814655	47.676967
50	13.978905	18.938323	26.276399	46.345598

Table III

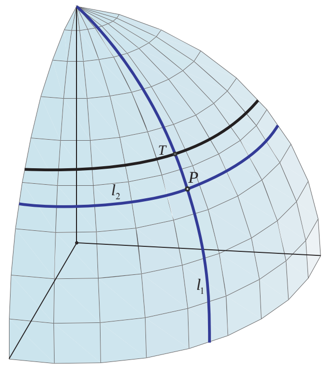
The electric field strength of the cube
in the center of the rounded vertices for different ratio r/a .

$\frac{r}{a}$	$\frac{E}{E_0}$	$k = \frac{E}{E_0}\sqrt{\frac{r}{a}}$
0.01	13.978905	1.39789
0.0075	15.808547	1.36906
0.005	18.938323	1.33914
0.0025	26.276399	1.31381
0.001	46.345976	1.46558

The relative error of the function of the potential along the rounded wedges and rounded vertices of the cube (Figs. 4a and 4b) are presented on Figs. 5, 6 and 7 and the electric field along the rounded vertices on Fig. 8.

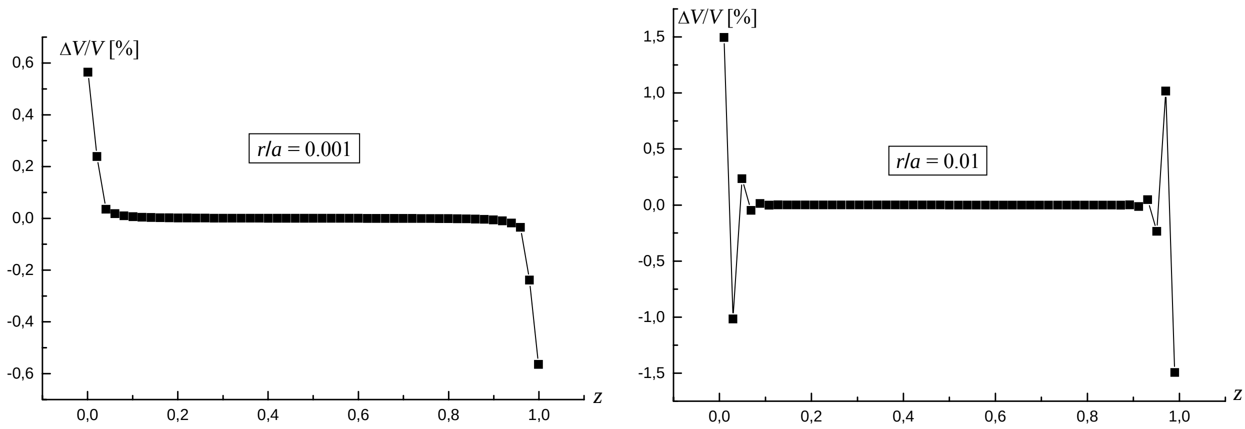


a)

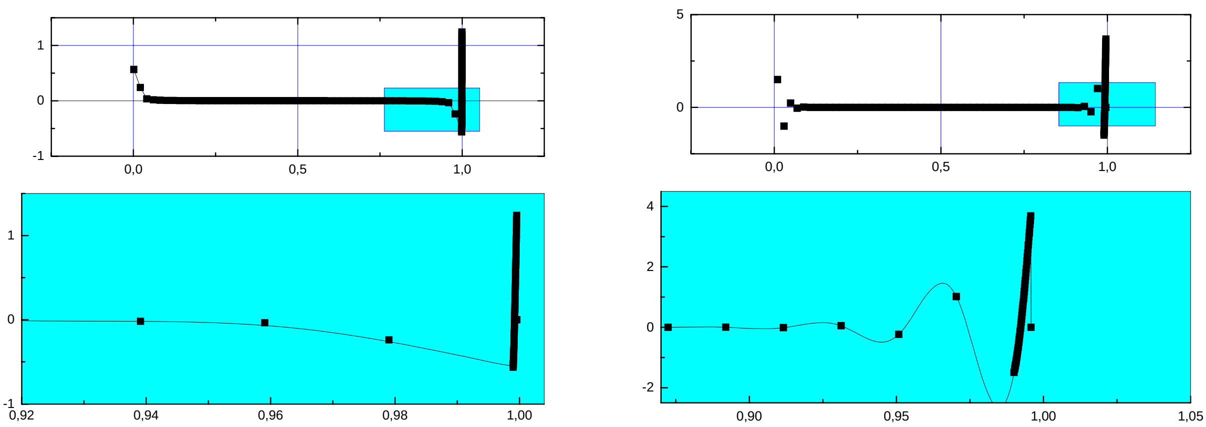


b)

Fig. 4 –Rouded wedges and rounded vertices of the cube (Fig.1).



a)



b)

Fig. 5 –Relative error of the function of the potential a) along the wedge RB and b) along the curve BT, Fig. 4a, for different ratio r/a. V is the potential of the metallic cube and $N = 50$.

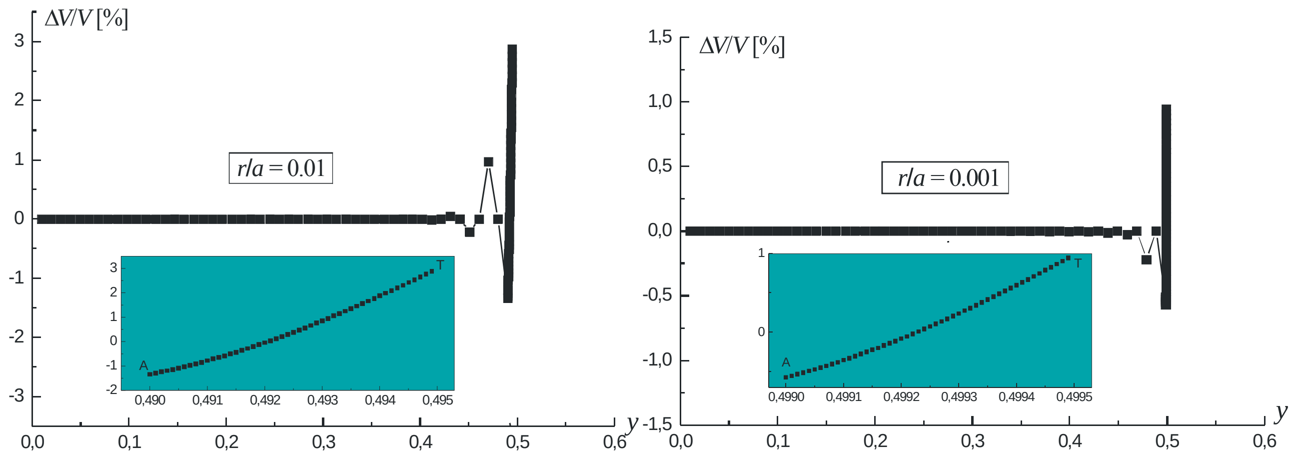
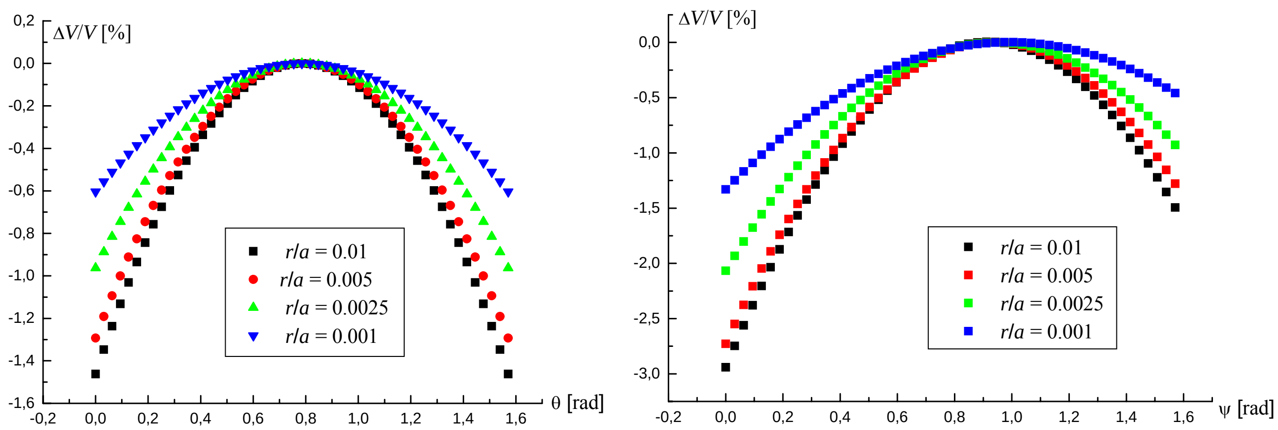


Fig. 6 –Relative error of the function of the potential along the wedge OA and curve AT, Fig. 4a, for different ratio r/a. V is the potential of the metallic cube and $N = 50$.



a) b)

Fig. 7 –Relative error of the function of the potential

a) along the curve l_2 and b) along the curve l_1, Fig. 4b,

for different ratio r/a and $N = 50$.

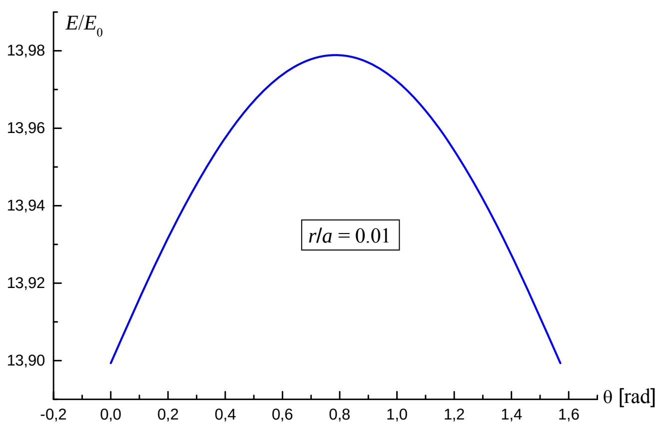


Fig. 8 –The electric field strength along the curve l_2, Fig. 4b.

CONCLUSION

In this paper using specific Equivalent source method the electric field in vicinity of the conducting cube with rounded wedges is determined. The method gives good convergence and accuracy depending of the number of used equivalent sources. The results presented in **Table III** show that intensity of the electric field strength in the vicinity of the wedges can be even 50 times as much as E_0 for specified ratio r/a. For Serbian region, the intensity of the atmospheric electric field during thunderstorm is $7-8\,\mathrm{kV/m}$ so it can be concluded that breakdowns can occur. (The breakdown field strength varies with electrode geometry and other factors, being $3\,\mathrm{kV/mm}$ for uniform field. In practice the electric field is rarely uniform, and so breakdown at lower field strength, typically $0.5-1\,\mathrm{kV/mm}$, is often observed.), Ref. 4.

The presented results can be applied to determinate the electric field strength in vicinity of the rounded wedges of the vehicles. The results show that even grounded tank trucks can be damaged by electric field breakdown due to atmospheric electric field during stormy weather.

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